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(54) **SYSTEM AND METHOD OF STERILELY CONNECTING FLUID PATHWAYS**

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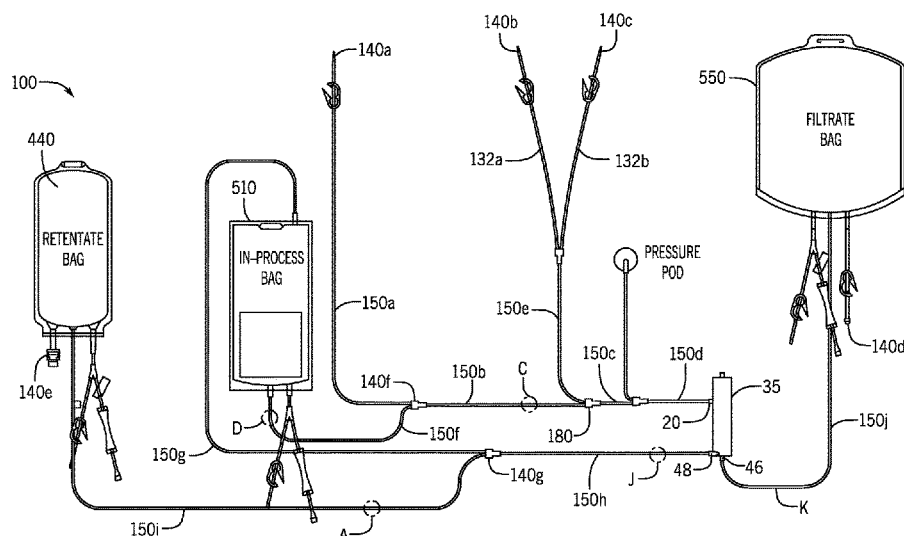
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(57) **ABSTRACT**

A sterile tube connector for a fluid circuit system comprising a housing. A first opening is configured to receive a first length of tubing in communication with a first chamber. A second opening is configured for communicating with the first chamber when the tube connector is in an open configuration but not in a closed configuration. The second opening is configured to reversibly engage a third opening to form a second chamber. The third opening is configured for communicating with a second length of tubing. A first portion of the housing forming the first opening comprises a material at least partially permeable to a sterilization energy source for sterilizing contents of the second chamber.

12 Claims, 9 Drawing Sheets



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B08B 9/027 (2006.01)
A61M 39/26 (2006.01)
A61M 39/16 (2006.01)

(52) **U.S. Cl.**

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 See application file for complete search history.

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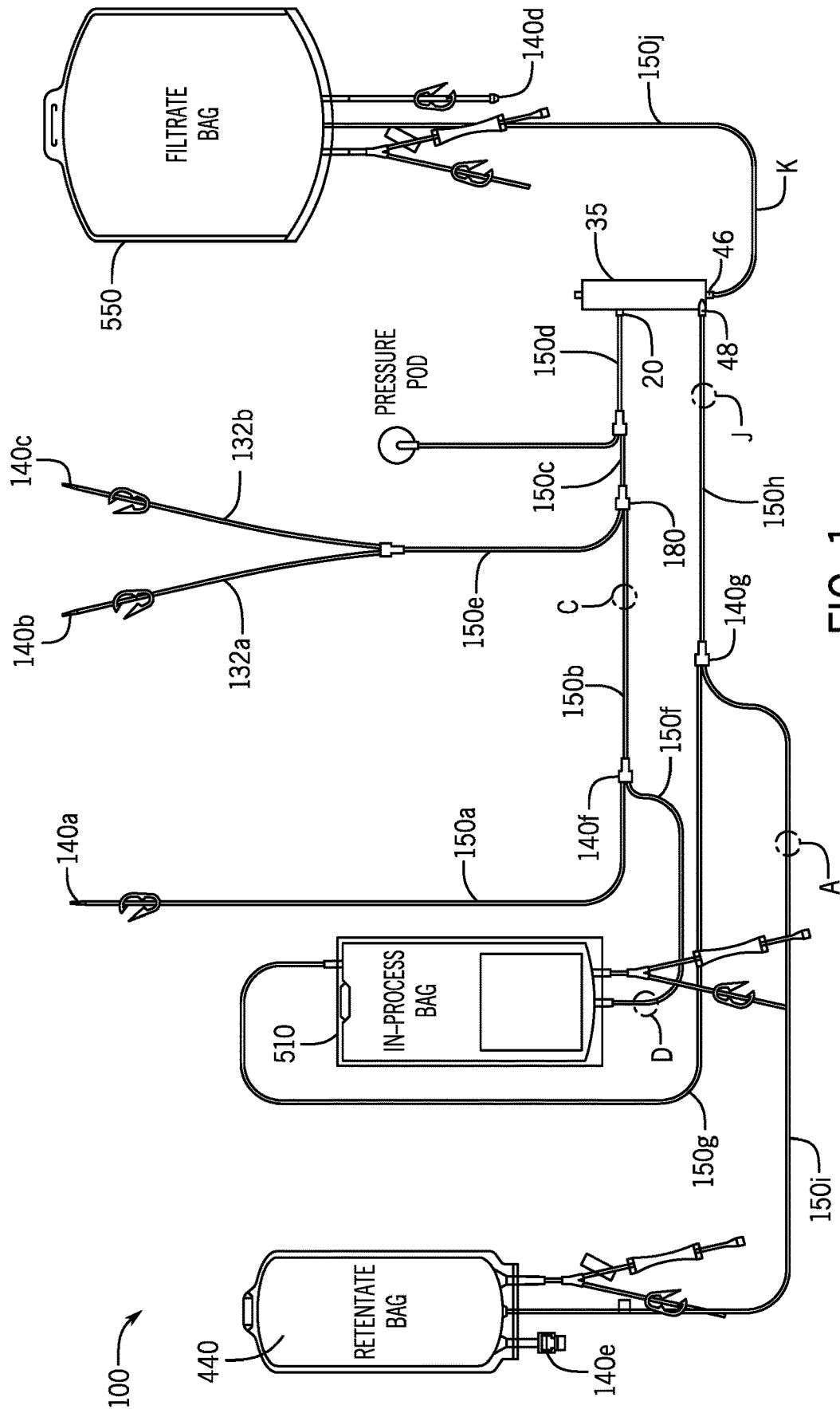


FIG. 1

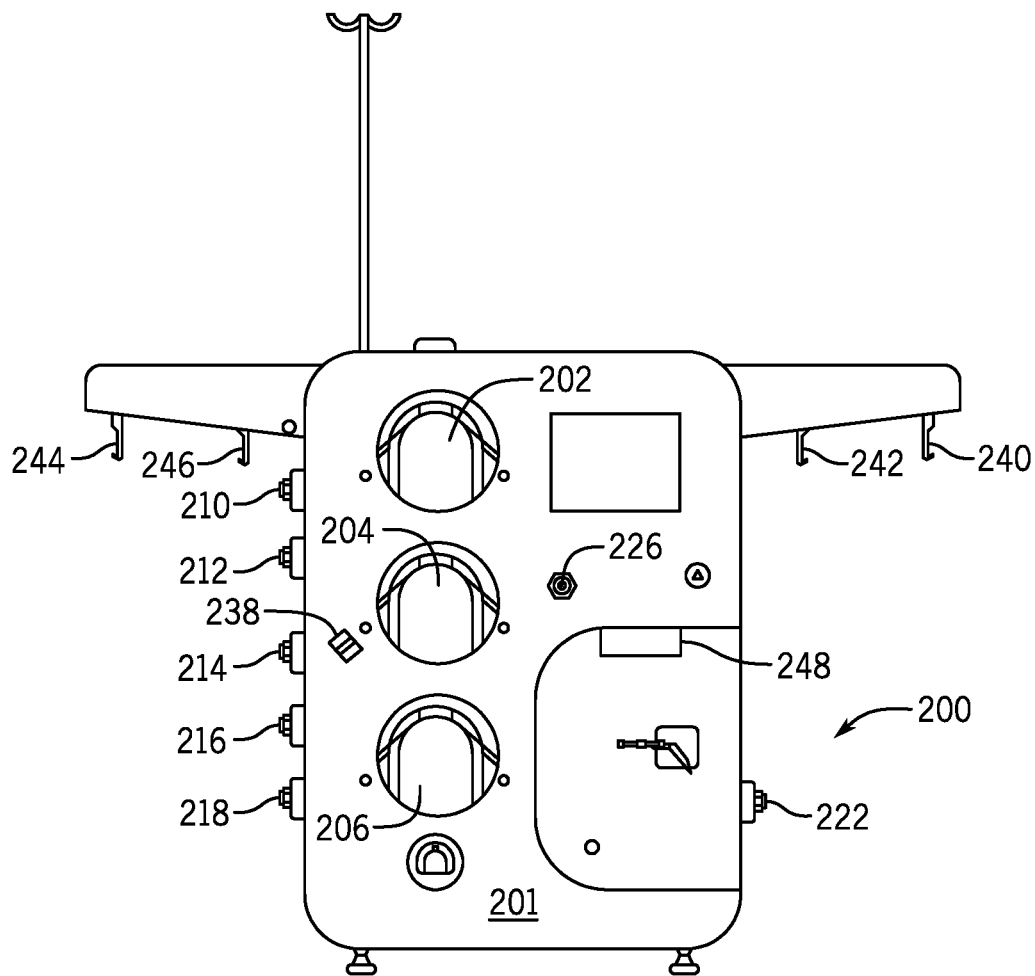


FIG. 2

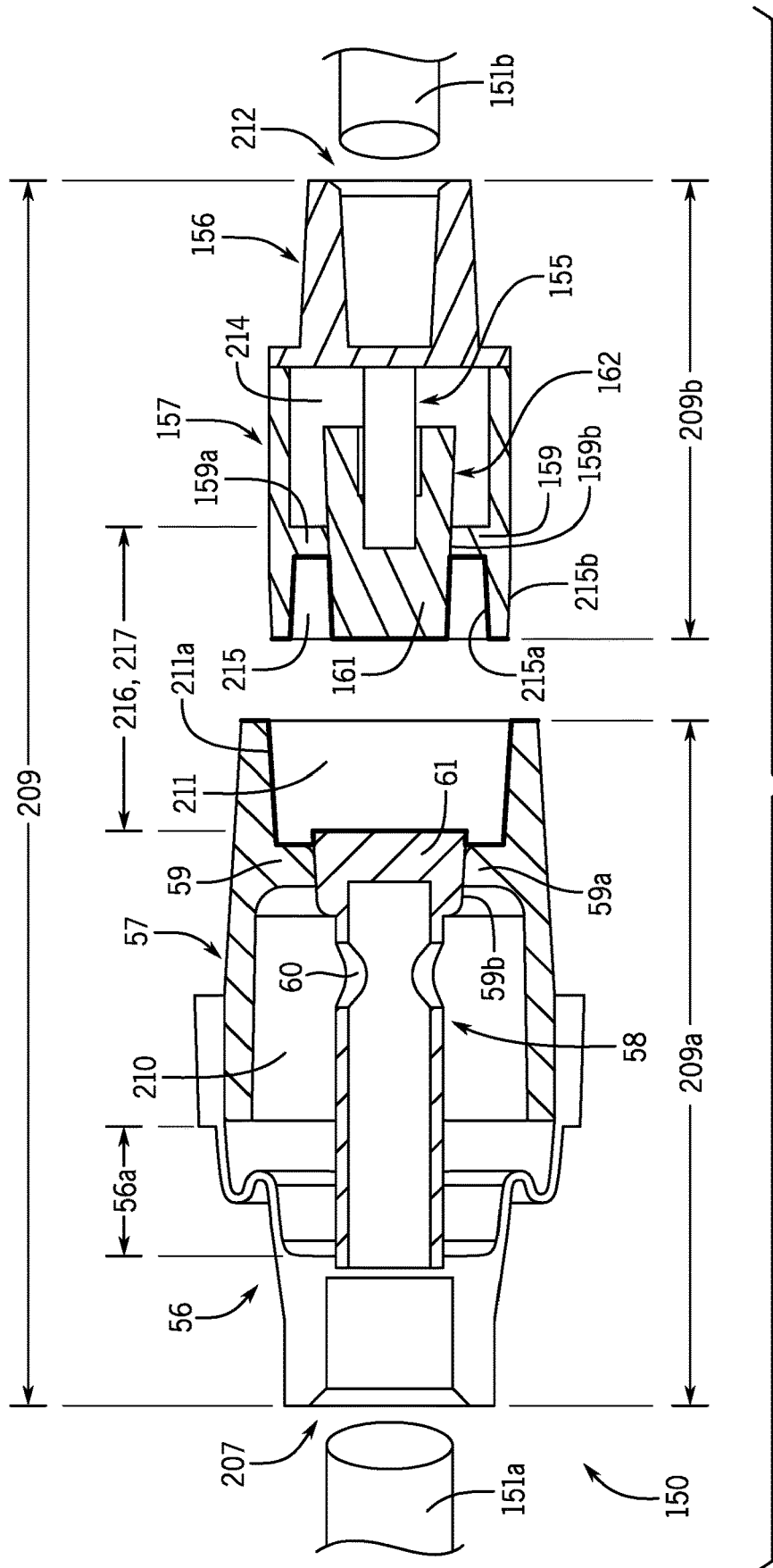


FIG. 3

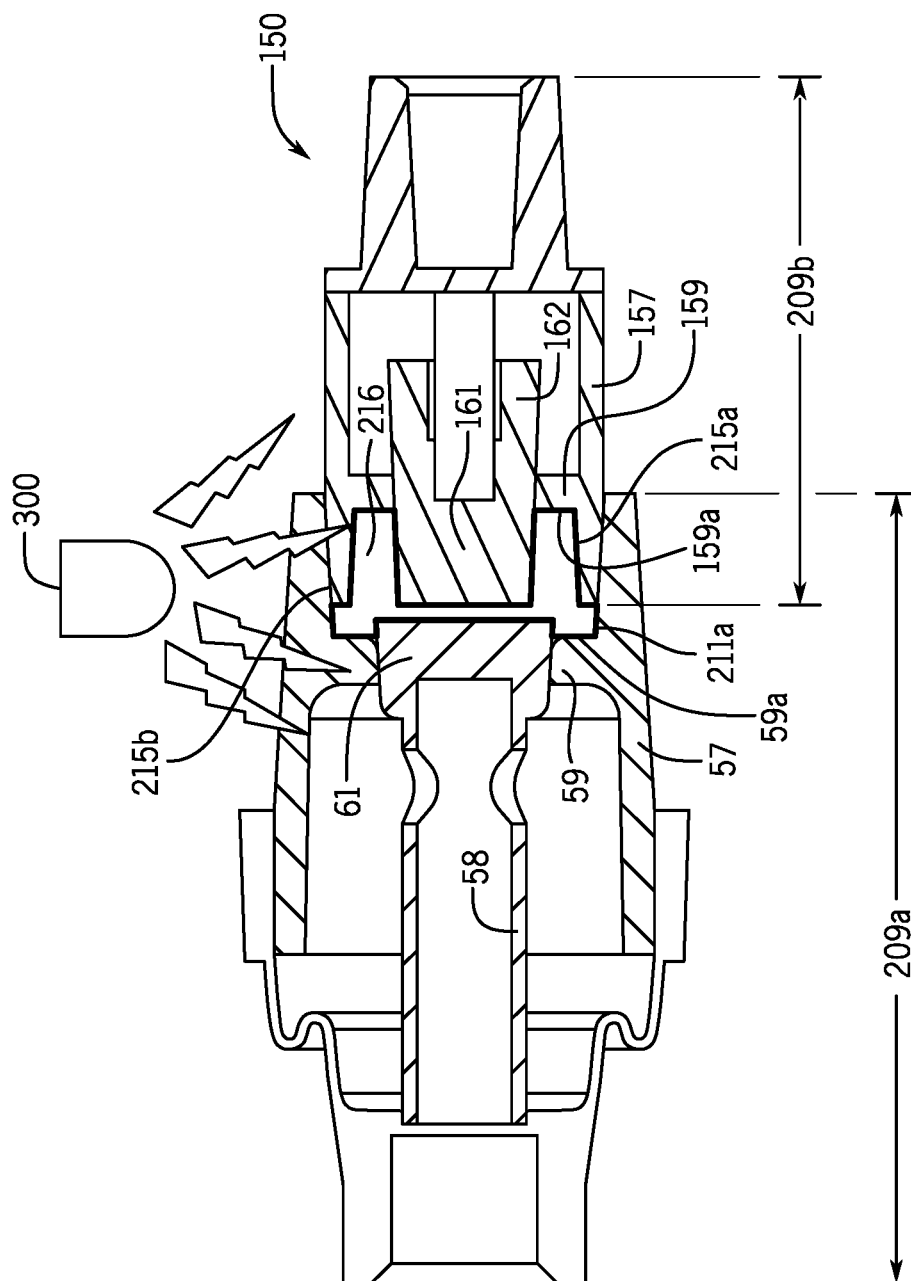


FIG. 4

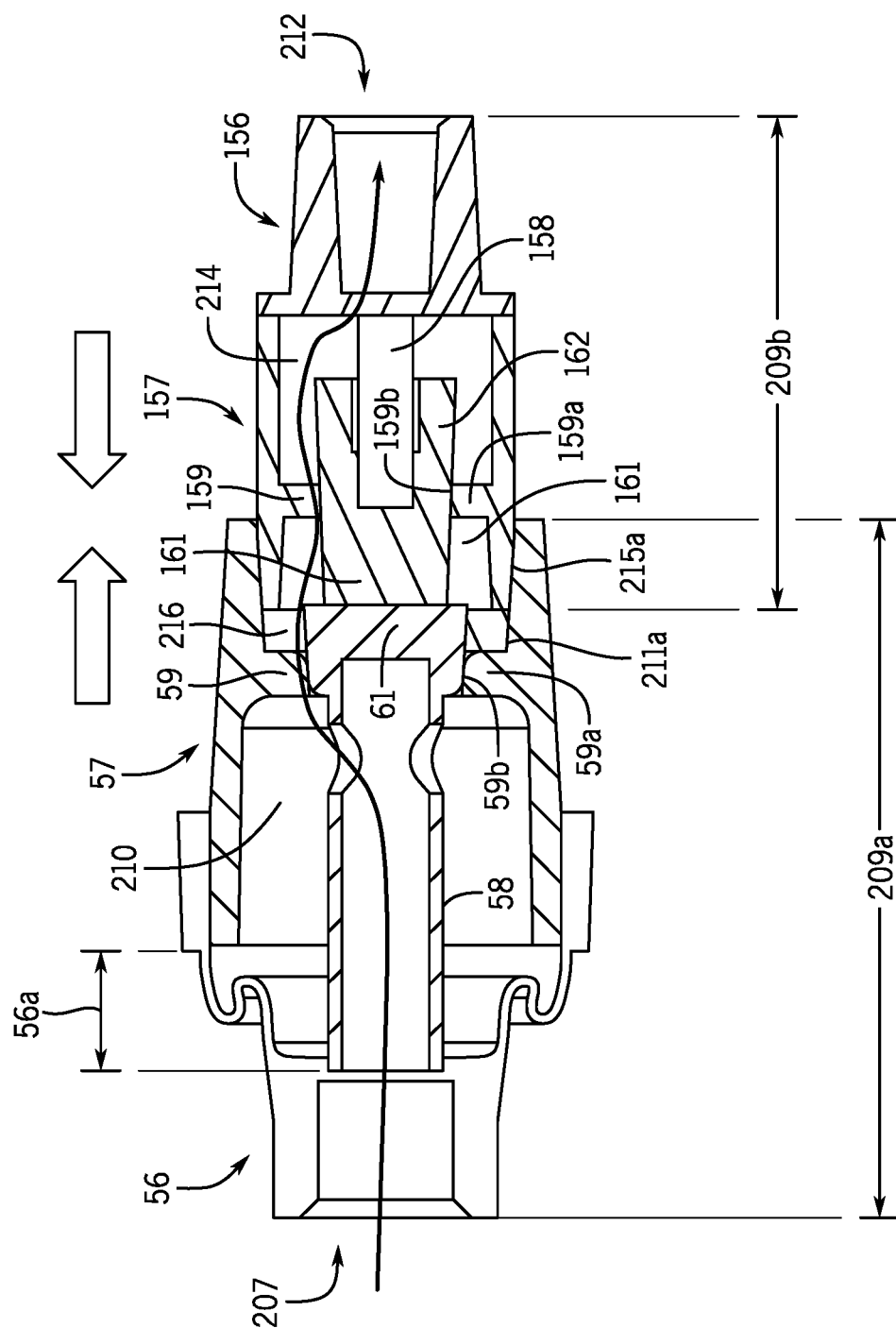
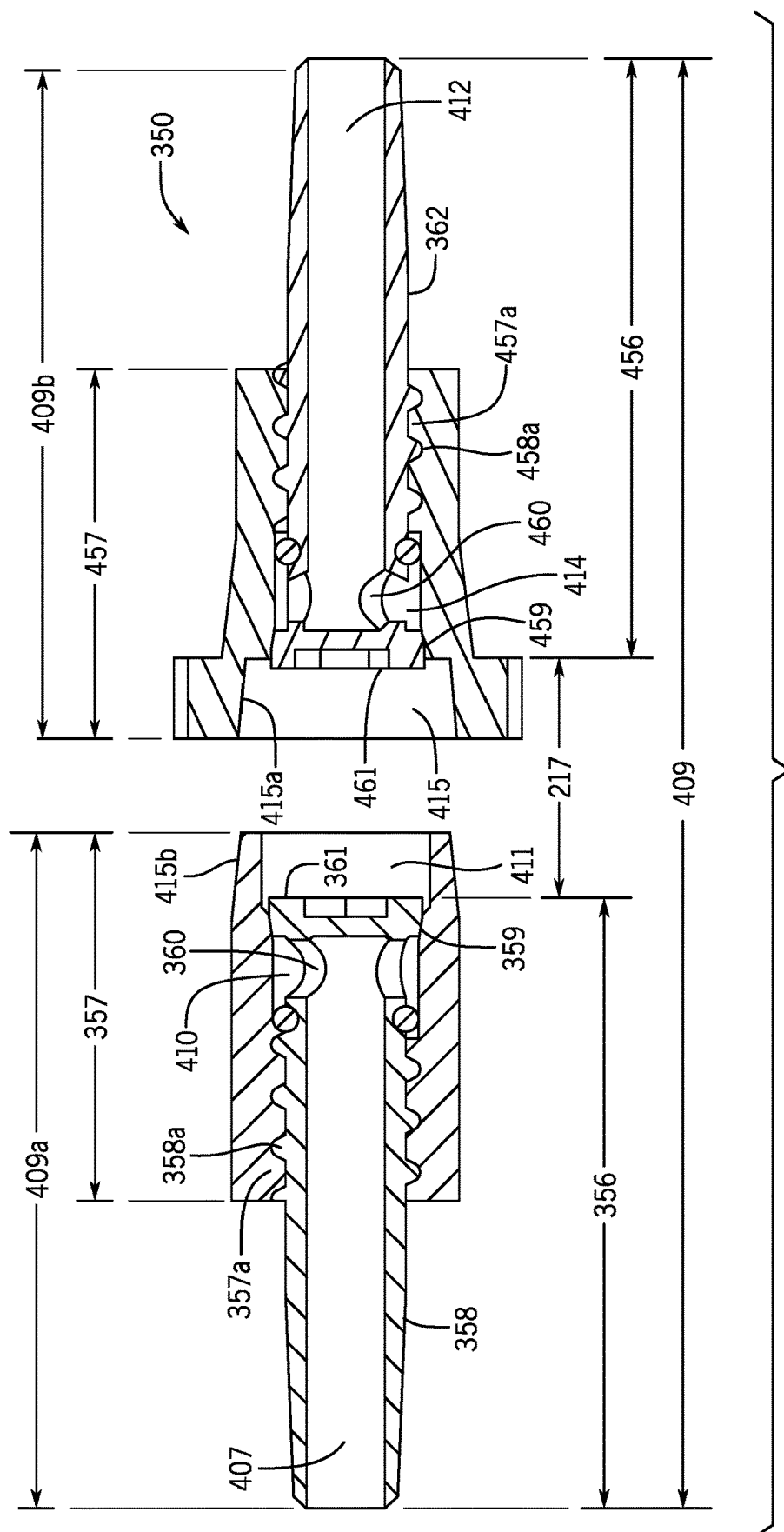


FIG. 5



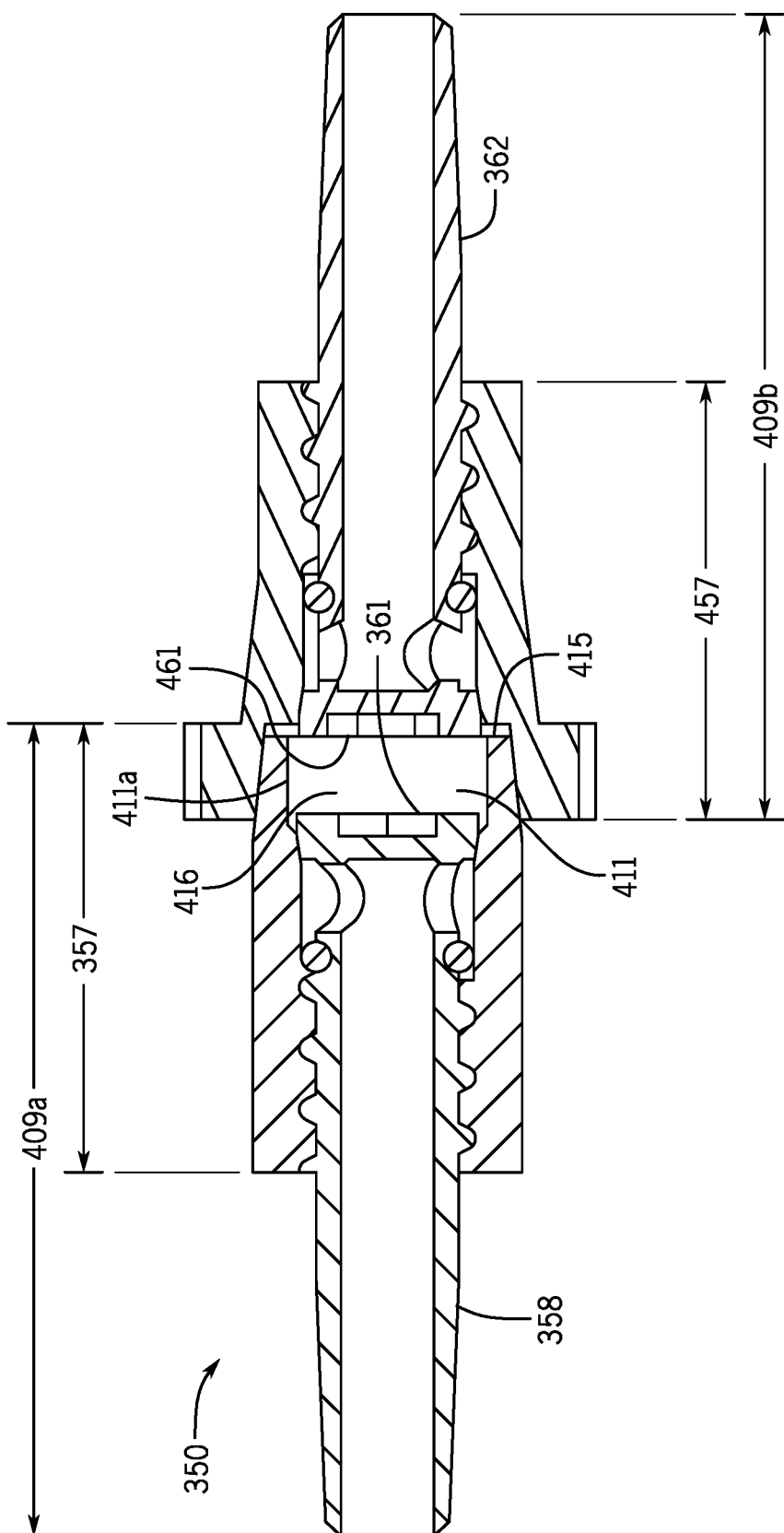
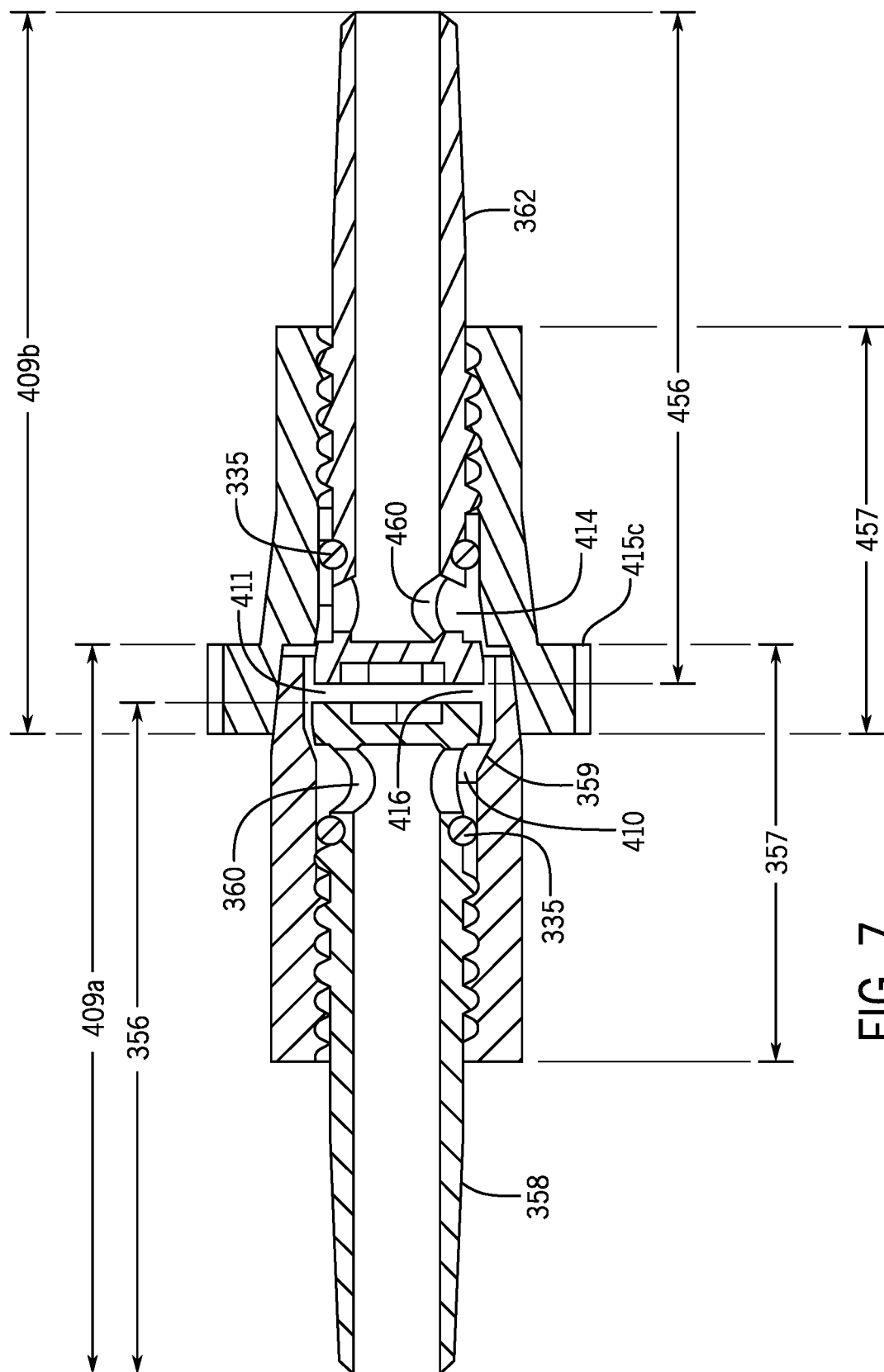


FIG. 6B



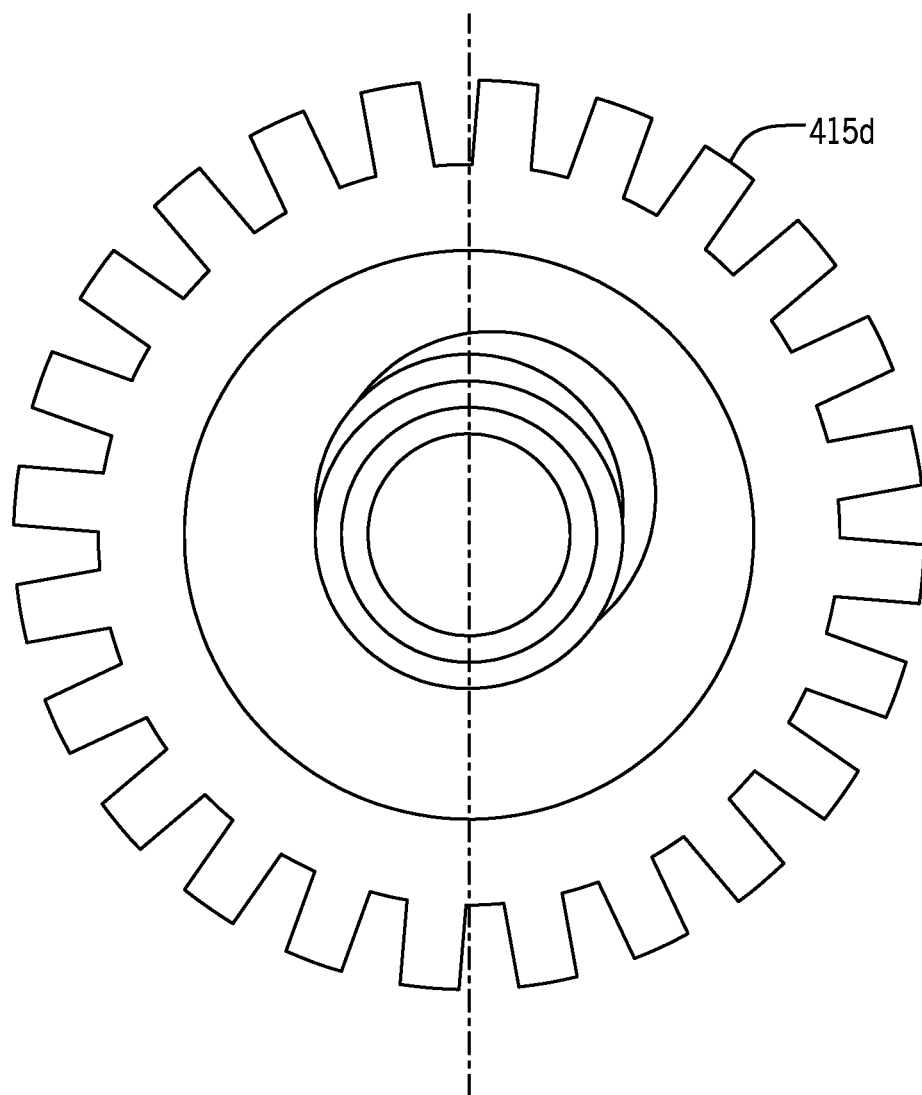


FIG. 8

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SYSTEM AND METHOD OF STERILELY CONNECTING FLUID PATHWAYS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent App. No. 62/608,995 filed Dec. 21, 2017, which is expressly incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

The present disclosure relates generally to systems and methods of sterilely connecting fluid pathways and, in particular to systems and methods for sterilely connecting fluid pathways with a reusable connector within a biological fluid circuit without excising fluid pathway material.

BACKGROUND

Processing or collection of biological fluid such as blood components, biological fluids, or medical fluids may involve using a reusable hardware and a disposable fluid circuit adapted for mounting or other association with the reusable hardware. The fluid circuit may include containers such as plastic containers, vials, and associated tubing that define flow paths through the circuit.

A disposable fluid circuit may include plastic containers and tubes that are pre-connected and pre-assembled to maintain sterility. In some processing systems and methods, containers including liquids such as anticoagulant, saline, wash solution, storage media, treating agents, biological fluids, etc., may likewise be pre-attached to the disposable fluid circuit, thereby creating a “closed” system. A “closed” system is one where the interior of the system, i.e., internal flow paths, separation chambers, etc., are not exposed or “opened” to the outside environment.

SUMMARY

According to an exemplary embodiment, the present disclosure is directed to a tube connector for a fluid circuit system comprising a housing. A first opening is configured to receive a first length of tubing in communication with a first chamber. A second opening is configured for communicating with the first chamber when the tube connector is in an open configuration but not in a closed configuration. A third opening is configured to receive a second length of tubing in communication with a second chamber. A fourth opening is configured for communicating with the second chamber when the tube connector is in the open configuration but not in the closed configuration. The second opening and the fourth opening are configured to engage each other to form a third chamber.

According to an exemplary embodiment, the present disclosure is directed to a method of sterilely connecting two fluid pathways. Provided is a first connector comprising a first chamber and a first open end and configured to connect to a first fluid pathway. The first chamber is configured to communicate with the first fluid pathway and the first open end when the first connector is in an open configuration but not in a closed configuration. Provided is a second connector comprising a second chamber and a second open end and configured to connect to a second fluid pathway. The second chamber is configured to communicate with the second fluid pathway and the second open end when the second connector is in an open configuration but not in a closed configuration.

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The first open end and the second open end are configured for engagement to form a third chamber. The third chamber is configured to communicate with the first chamber when the first connector is in the open configuration but not in the closed configuration and communicate with the second chamber when the second connector is in the open configuration but not in the closed configuration. The first open end and the second open end forming the third chamber comprises a first material at least partially permeable to a sterilization energy source for sterilizing contents of the third chamber. A first portion of the first connector surrounding the first chamber and a second portion of the second connector surrounding the second chamber comprise a second material less permeable to the sterilization energy source. Applying the sterilization energy source to the third chamber upon engagement of the first and second open ends when the first and second connectors are in the closed configuration and subsequently opening the first and second connectors to the open configuration allows sterile fluid from the first chamber to cross the third chamber into the second chamber while maintaining sterility.

According to an exemplary embodiment, the present disclosure is directed to a sterile tube connector for a fluid circuit system comprising a housing. A first opening is configured to receive a first length of tubing in communication with a first chamber. A second opening is configured for communicating with the first chamber when the tube connector is in an open configuration but not in a closed configuration. The second opening is configured to reversibly engage a third opening to form a second chamber. The third opening is configured for communicating with a second length of tubing. A first portion of the housing forming the first opening comprises a material at least partially permeable to a sterilization energy source for sterilizing contents of the second chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

Features, aspects, and advantages of the present embodiments will become apparent from the following description, appended claims, and the accompanying exemplary embodiments shown in the drawings, which are briefly described below.

FIG. 1 is a schematic view of a disposable fluid circuit that may be used in combination with a reusable processing apparatus, according to an exemplary embodiment;

FIG. 2 is an enlarged view of a front panel of a reusable processing apparatus, according to an exemplary embodiment;

FIG. 3 is a longitudinal cross section view of sub-housings of a connector, according to an exemplary embodiment;

FIG. 4 is a longitudinal cross section view of the connector of FIG. 4 in which the sub-housings are in engagement, according to an exemplary embodiment;

FIG. 5 is a longitudinal cross section view of the connector of FIGS. 3-4 in which fluid communication is open between the sub-housings, according to an exemplary embodiment;

FIG. 6A is a longitudinal cross section view of sub-housings of a connector, according to another exemplary embodiment;

FIG. 6B is a longitudinal cross section view of the connector of FIG. 6A in which the sub-housings are in engagement, according to an exemplary embodiment;

FIG. 7 is a longitudinal cross section view of the connector of FIGS. 6A-6B in which fluid communication is open between the sub-housings, according to an exemplary embodiment; and

FIG. 8 is a lateral cross section view of a connector portion of the connector of FIGS. 6A, 6B, and 7, according to an exemplary embodiment.

DETAILED DESCRIPTION

There are several aspects of the present subject matter which may be embodied separately or together in the devices and systems described and claimed below. These aspects may be employed alone or in combination with other aspects of the subject matter described herein, and the description of these aspects together is not intended to preclude the use of these aspects separately or the claiming of such aspects separately or in different combinations as set forth in the claims appended hereto.

In the course of biological fluid processing, a variety of fill/finish operations, and/or any fluid processing requiring sterile connection of fluid paths, one common method for sterilely connecting fluid paths is by use of a sterile weld device, which takes two tubing segments of compatible sizes and materials and performs a welding operation in which the segments of tubing are clamped, cut, aligned with each other, and melted to fuse the two segments together. An operator may manually load tubing segments into the sterile weld device serially for each welding operation. Using a sterile weld device may require additional disposable components, e.g., blades, cartridges, and may include some portion of a tubing segment being excised, thereby shortening the tubing segment with each sterile weld operation. In instances in which fluidic circuits are frequently and routinely attached to multiple other circuits, e.g., fill/finish operations in which a bulk fluid within a circuit is aliquoted into several, separate containers/fluidic circuits, sterile welding may call for each circuit to have long lengths of tubing to accommodate tubing length consumption with each welding event.

Some embodiments may decrease reliance on manual interventions common even in automated processes of multiple welding operations involving complex loading and unloading procedures.

Some embodiments may minimize or obviate tracking tubing lengths being consumed for multiply-welded tubing segments.

Some embodiments may enable fluid circuit connections even when the segments to be connected are not made of compatible materials or employ dissimilar sizes or are otherwise not easily implemented with welding systems."

It may be desirable to durably create and maintain sterile fluid pathways between two closed fluidic circuits without compromising sterility, without taking on aseptic risk, and without consuming tubing segments with each connection event.

Some embodiments may obviate the use of additional disposable components in sterilely connecting fluid pathways together.

Some embodiments may allow for repeated sterile connections between two fluid pathway segments without shortening segment lengths each time the connection is performed.

Some embodiments may allow fluid circuits to have shorter lengths of tubing without accommodating tubing length consumption with each welding event.

Some embodiments may decrease variability in the pathway joining process and be conducive to automation.

Systems and methods for sterile processing of fluid are disclosed herein. The systems disclosed may include a fluid processing apparatus and one or more disposable processing circuits adapted for association with the processing apparatus. The processing apparatus may be any apparatus for processing of fluids in sterile environments. Examples include apparatuses for cell processing, apheresis, infusion, transfusion, fractionation, cell washing, dialysis, molecular and medical diagnostics, forensics, anesthesia, etc.

While primarily described herein with reference to a fluid processing system used in a blood separation machine, the described concepts may be applied to any other type of fluid circuit system and/or fill/finish operations in which sterile connection is desired. The processing apparatus may be capable of effecting the separation of a biological fluid that includes biological cells into two or more components or fractions. Thus, the processing apparatus may generate conditions which allow for the separation of a biological fluid into selected components or fractions. In one embodiment, an apparatus that uses a spinning porous membrane to separate one component from other components may be used for separating biological fluid into its constituent components or fractions. An example of a spinning membrane may be found in U.S. Pat. No. 5,194,145 to Schoendorfer and International Application No. PCT/US2012/028492, filed Mar. 9, 2012, both of which are incorporated herein in their entireties, although any suitable membrane separator may be used. In another embodiment, an apparatus that uses centrifugal separation principles to separate one component from other components may be used for separating biological fluid into its constituent components or fractions. An exemplary centrifugal separator is disclosed in U.S. Pat. No. 5,868,696, which is incorporated by reference in its entirety, although any suitable centrifugal separator may be used. In other embodiments, the described concepts may be applied to blood pack units, transfer packs, or other static fluid systems.

Both membrane separation and centrifugal separation systems may involve a durable processing system or device used in combination with a disposable processing set or circuit. The durable processing system may include a pump assembly that interacts with one or more of the components of the disposable circuit to draw blood or other bodily fluid from a blood source and move the blood or bodily fluid to another location within the disposable circuit by moving fluid through a fluid flow path.

Referring now to FIG. 1, a fluid circuit 100 is shown, according to an exemplary embodiment. In various embodiments, fluid circuit 100 may be configured to associate with a cell processing machine 200 (FIG. 2) that separates source blood into blood components. For example, a cell processing device 200 may include a membrane separator 35 or other blood separation device that processes whole blood or other suspensions of biological material into its constituent components (e.g., red blood cells, plasma, platelets, etc.). The cell processing device may associate with fluid circuit 100 which may be configured to convey fluid to and from the separator or other separation device to/from/between multiple collection containers 440, 510, 550. Such fluids may be routed in fluid circuit 100 via lengths of fluid pathways or tubing 150a-j. In an embodiment in which biological fluids such as blood are handled, tubing 150a-j may be formed of non-reactive materials and may be configured for a single use (e.g., intended to be disposed after each use). In some embodiments, tubing 150a-j may also be formed of a

relatively flexible material, such as PVC or silicone. In one exemplary embodiment, tubing **150a-j** may comprise an outer diameter of less than 3 cm with a hardness of approximately 70 shore A.

Tubing **150a-j** may be coupled to the various components of fluid circuit **100** and/or to other lengths of tubing **150a-j** via connectors **140a-g**. For example, tubing **150a** and its corresponding connector **140a** may be connected to a container **440** via connector **140e**. In various embodiments, connectors **20** may be inline connectors coupling two lengths of tubing **150a-j** together, Y-connectors or T-connectors coupling more than two lengths of tubing **150a-j** together, connectors configured to couple a length of tubing **150a-j** to the cell processing device **200**, connectors configured to couple a length of tubing **150a-j** to a collection container **440**, **510**, **550**, or a connector for coupling a length of tubing **150a-j** to any number of lengths of tubing **150a-j**. A length of tubing **150a-j** and a corresponding connector **140a-g** may be bonded together to form a hermetic seal, thereby preventing or minimizing the escape of fluid from fluid circuit **100** where the length of tubing **150a-j** and the connector **140a-g** are joined. After the collection of the fluids is complete, a collection container **440**, **510**, **550** may be separated from fluid circuit **100** by disconnecting connector **140a-g** from a counterpart connector **140a-g** of the fluid circuit **100**.

Referring now to FIG. 3, a longitudinal cross section view of a connector **150** is shown, according to an exemplary embodiment. Connector **150** may be used in a fluid circuit, such as fluid circuit system **100** shown in FIG. 1 or in another such fluid circuit. Connector **150** may generally be configured to receive and retain inserted lengths of tubing **151a**, **151b** or otherwise form a hermetic seal to prevent fluid from leaving the fluid circuit. In one embodiment, tubing **151a**, **151b** may be coupled to the connector **150** with a solvent adhesive. In other embodiments, tubing **151a**, **151b** may be coupled to connector **150** by another suitable method, such as a welded connection or a mechanical connection (e.g., clamped or compressed between two portions of connector **150**), or connector **150** may be over- or under-molded around tubing **151a**, **151b**. In one embodiment, a portion of the connector **150** may be constructed using a relatively stiff material, such as a medium durometer (e.g., 40-80A durometer) PVC material, in comparison to that of tubing **151a**, **151b**.

The connector **150** may comprise a generally hollow and cylindrical housing **209**. In one embodiment, the housing **209** may comprise a sub-housing **209a** corresponding to one fluid pathway **151a** and another sub-housing **209b** corresponding to another fluid pathway **151b**. Sub-housings **209a** and **209b** may be configured to reversibly or irreversibly engage each other in sealing engagement. Each sub-housing **209a** and **209b** may also function as a connector per se, configured for engagement with any other connector having a complementary shape.

Sub-housing **209a** may comprise a socket segment **56** connected to a connector segment **57**. The socket segment **56** may comprise an opening **207** configured to receive a fluid pathway **151a**, e.g. a length of tubing. The opening **207** may have any generally hollow shape (e.g., circular, square, ovoid, etc.), depending on the shape of the cross-section of the fluid pathway to be inserted. The opening **207** may be in communication with a chamber **210** formed by the socket segment **56** and the connector segment **57**. The connector segment **57** may comprise a valve **59** controlling fluid flow between the chamber **210** and an opening **211** of the connector segment **57**. The valve **59** may comprise a wall **59a**

separating the chamber **210** and the opening **211** that is generally perpendicular to the length of the tubing **151a** and includes an aperture **59b**. Communication between the opening **207** of the socket portion **56** and the chamber **210** may be effected by a hollow channel **58** (e.g., plunger) that extends from the opening **207** of the socket portion **56** through the chamber **210** into the aperture **59b** and is blocked at a tapered end **61**. The channel **58** may comprise at least one orifice **60** disposed within the chamber **210** that allows fluid communication between the opening **207** and the chamber **210**. The tapered end **61** of the plunger **58** may be disposed through the aperture **59b** such that the tapered end **61** and the aperture **59b** form a hermetic seal when the first sub-housing is in a closed configuration. The diameter of the tapered end **61** disposed on the chamber side of the aperture **59b** may be smaller than the diameter of the aperture **59b**, while the diameter of the tapered end **61** disposed on the side of the aperture of the opening **211** may be larger than the diameter of the aperture **59b**. The tapering of the end **61** of the plunger **58** may ensure that the end **61** does not retract back through the aperture **59b** towards the chamber **210**.

An open configuration of the first sub-housing **209a** may be effected by compression of the sub-housing **209a** relative to the plunger/channel **58**. In one embodiment, the plunger **58** may be attached to a tension spring (not illustrated) of the socket portion **56** such that in the resting state of the sub-housing **209**, tension within the plunger **58** maintains a closed configuration, driven by a spring force pulling the plunger **58** towards the opening **207** and opposed by the valve **59** holding the tapered end **61** in place. FIG. 3 shows the socket portion **56** having a compliant segment **56a**. The compliant segment **56a** may be manually compressible from the resting state. Although FIG. 3 shows the socket portion **56** including the compliant segment **56a**, a compliant segment may be incorporated into either or both of the portions **56** and **57**. Compression of the compliant segment **56a** may induce translational motion of the valve **59** towards the opening **207** relative to the tapered end **61** of the plunger **58**. Translational motion induced by compression may open the seal between the tapered end **61** and the aperture **59b** due to the difference in diameters between the end **61** and the aperture **59b** to allow fluid flow between the chamber **210** and the opening **211**.

Sub-housing **209b** may comprise a socket segment **156** connected to a connector segment **157**. The socket segment **156** may comprise an opening **212** configured to receive a fluid pathway **151b**, e.g. a length of tubing. The opening **212** may be in communication with a chamber **214** formed by the socket segment **156** and the connector segment **157**. The connector segment **157** may comprise a valve **159** controlling fluid flow between the chamber **214** and an opening **215** of the connector segment **157**. The valve **159** may comprise a wall **159a** separating the chamber **214** and the opening **215** that is generally perpendicular to the length of the tubing **151b** and includes an aperture **159b**. A compressible member **158** attached to a stopper **162** having a tapered end **161** may extend from the socket portion **156** through the chamber **214** into the aperture **159b** until the tapered end **161** seals the aperture **159b**. The tapered end **161** of the stopper **162** may be disposed through the aperture **159b** such that the tapered end **161** and the aperture **159b** form a hermetic seal when the sub-housing **209b** is in a closed configuration. The diameter of the tapered end **161** disposed on the chamber side of the aperture **159b** may be larger than the diameter of the aperture **159b**, while the diameter of the tapered end **161**

disposed on the side of the opening **215** may be smaller than the diameter of the aperture **159b**.

An open configuration of the sub-housing **209b** may be effected by compression of the compressible member **158** relative to the sub-housing **209b**. In one embodiment, the compressible member **158** may be attached to a compression spring (not illustrated) of the socket portion **156** such that in the resting state of the sub-housing **209b**, compression within the compressible member **158** maintains a closed configuration, driven by a spring force pushing the stopper **162** towards the opening **215** and opposed by the valve **159** holding the tapered end **161** in place. FIG. **3** shows the socket portion **56** having a compliant segment **56a**. Compression of the compressible member **158** may induce translational motion of the compressible member **158** and stopper **162** towards the opening **212** relative to the valve **159**. Translational motion induced by compression may open the seal between the tapered end **161** and the aperture **159b** due to the difference in diameters between the end **161** and the aperture **159b** to allow fluid flow between the chamber **214** and the opening **215**.

Referring now to FIG. **4**, a longitudinal cross section view of the connector **150** is shown in which sub-housings **209a** and **209b** are engaged with each other in sealing engagement, according to an exemplary embodiment. FIG. **4** depicts both sub-housings **209a** and **209b** in closed configurations. The opening **211** of the connector segment **57** of the sub-housing **209a** and the opening **215** of the connector segment **157** of the sub-housing **209b** may be configured to form an enclosed chamber **216**. The inner surface **211a** of the connector portion **57** forming the opening **211**, the wall **59a** of valve **59**, the tapered end **61** of plunger **58**, the inner surface **215a** of the connector portion **157** forming the opening **215**, the wall **159a** of valve **159**, and/or the tapered end **161** of stopper **162** may together form the walls of the enclosed chamber **216**. The connector segments **57** and **157** may be configured such that the outer surface of one segment forms a friction fit, interference fit, Luer fit, threaded fit, etc., with the other segment. For example, the outer surfaces **215b** of the connector segment **157** may be configured to hermetically engage with the inner surfaces **211a** of the connector segment **57**.

Once the chamber **216** is hermetically sealed, surfaces **59a**, **61**, **159a**, **161**, **211a**, **215a** previously open to the atmosphere may be sterilized. A sterilization energy source **300** configured with a known germicidal dose may be applied to the newly formed chamber **216**. In one embodiment, the sterilization energy source may comprise a UVC emitter (e.g., LED, CFL bulb). In another embodiment, the sterilization energy source may comprise heat, steam, ebeam, gamma rays, etc.

It may be desirable to selectively apply sterilization energy to the chamber **216** while minimizing exposure of the germicidal dose of energy to other portions of the connector **150**. For example, the socket portion **56** of sub-housing **209a** and the socket segment **156** of sub-housing **209b** and any fluid contained therein may not require sterilization and may comprise biological materials sensitive to the sterilization energy. Therefore, it may be desirable for the socket portions **56** and **156** to comprise a material with low permeability to the sterilization energy and for the connector portions **57** and **157** to comprise a material with high permeability to the sterilization energy. In an embodiment in which the sterilization energy source comprises UVC, the connector portions **57** and **157** may comprise a substantially UVC-transparent material, such as cyclic olefin copolymer (COC), poly(methyl methacrylate) (PMMA), polymethylpentene

(PMP or TPX), and/or quartz glass, and the socket portions **56** and **156** may comprise a substantially UVC-opaque material, such as polycarbonate, PVC, and/or ABS (acrylonitrile butadiene styrene). Opacity may be accomplished or enhanced by colorants and/or pigments. In an embodiment in which the sterilization energy source comprises heat, steam, ebeam, gamma rays, etc., connector portions **56**, **57**, **156**, and **157** may be comprised of heat compatible material, such as polycarbonate, PVC, and/or ABS, and the socket portions **56** and **156** may further comprise a substantially heat transmissive material and may even comprise heat resistive material, such as polyurethane and/or silica aerogel. Referring to FIG. **3**, in one embodiment, connector portions **57** and **157** may be made of one material permeable to the sterilization energy for a segment **217** surrounding the sterilization chamber **216** and another material less permeable to the sterilization energy for the remaining portions of connector portions **57** and **157**.

Referring to FIG. **5**, once the chamber **216** and corresponding surfaces **59a**, **61**, **159a**, **161**, **211a**, **215a** have been sterilized, fluid communication may be opened between chambers **210** and **216**. Sub-housing **209a** may be shifted to an open configuration by breaking the seal between the tapered end **61** of the plunger **58** and the aperture **59b** by compressing the sub-housing **209a** relative to the plunger/channel **58**, which in one embodiment may be implemented by compressing the compliant segment **56a** of the socket portion **56**. Translational motion of the valve **59** may be induced towards the opening **207** relative to the tapered end **61** of the plunger **58** and thereby open fluid flow from the chamber **210** to the chamber **216**. Fluid from the sub-housing **209a** may flow from within the channel **58** through the orifice **60** into the chamber **210** through the valve aperture **59b** and into the sterilization chamber **216**.

Sub-housing **209b** may be shifted to an open configuration by breaking the seal between the tapered end **161** of the stopper **162** and the aperture **159b**. Once sub-housing **209a** is shifted to an open configuration and the translational motion of the valve **59** is induced towards the opening **207** relative to the tapered end **61** of the plunger **58**, the engagement (friction fit, interference fit, Luer fit, threaded fit, etc.) between the connector segment **157** and the connector segment **57** may pull sub-housing **209b** towards the compliant segment **56** while the tapered end **61** of the plunger **58** exerts an opposite force against the stopper **162**. The opposite force against the stopper **162** may induce compression of the compressible member **158** of the socket segment **156**, leading to translational motion of the compressible member **158** and stopper **162** towards the opening **212** relative to the valve **159**, opening the seal between the tapered end **161** and the aperture **159b**. Fluid from the sterilization chamber **216** may flow through the valve aperture **159b** into the chamber **214** and into the opening **212** of sub-housing **209b**.

When fluid communication is no longer desired and/or different fluid connections are desired, the sub-housings **209a** and **209b** may be disconnected by relieving compression of compliant segment **56a** and compressible member **158** to shift both connectors to the closed configuration. The engagement between the connector segment **157** and the connector segment **57** forming the sterilization chamber **216** may be severed, and the connectors **209a** and **209b** may be re-used with other connections.

Referring now to FIG. **6A**, a longitudinal cross section view of another embodiment of a connector **350** is shown. Connector **350** may generally be configured to receive and retain lengths of tubing or otherwise form a hermetic seal to prevent fluid from leaving as sterile system. The connector

350 may comprise a generally hollow and cylindrical housing **409**. In one embodiment, the housing **409** may comprise a sub-housing **409a** corresponding to one fluid pathway another sub-housing **409b** corresponding to another fluid pathway. Sub-housings **409a** and **409b** may be configured to reversibly or irreversibly engage each other in sealing engagement. Each sub-housing **409a** and **409b** may also function as a connector per se, configured for engagement with any other connector having a complementary shape.

Sub-housing **409a** may comprise a socket segment **356** connected to a connector segment **357**. The socket segment **356** may comprise an opening **407** configured to receive a fluid pathway, e.g. a length of tubing. The opening **207** may be in communication with a chamber **410** formed by the socket segment **356** and the connector segment **357**. The connector segment **357** may comprise a small diameter portion **359** disposed between the chamber **410** and an opening **411** of the connector segment **357**. Communication between the opening **407** of the socket portion **356** and the chamber **410** may be effected by a hollow channel **358** that extends from the opening **407** of the socket portion **356** through the chamber **410** past the small diameter portion **359** and is blocked at an end **361**. The channel **358** may comprise at least one orifice **360** disposed within the chamber **410** that allows fluid communication between the opening **407** and the chamber **410**. The end **361** of the channel **358** may cover the small diameter portion **359** such that the end **361** and the small diameter portion **359** form a hermetic seal separating the chamber **410** and the opening **411** when the first sub-housing is in a closed configuration. The diameter of the end **361** disposed on the chamber side of the small diameter portion **359** may be smaller than the diameter of the small diameter portion **359**, while the diameter of the end **361** disposed on the side of the opening **411** may be larger than the diameter of the small diameter portion **359**. The differences in diameters of the end **361** of the channel **358** may ensure that the end **361** does not retract back into the chamber **410**.

An open configuration of the first sub-housing **409a** may be effected by rotation of the socket segment **356** and connector segment **357** relative to each other. In one embodiment, the channel **358** may have outer threads **358a** configured to mate with corresponding inner threads **357a** of the connector portion **357** such that in the closed configuration of the sub-housing **409a**, outer and inner threads **358a** and **357a** are tightly fastened, with the end **361** tightly sealed against the small diameter portion **359**. Rotation of the socket segment **356** and connector segment **357** relative to each other may induce translational motion of the channel **358** and end **361** towards the opening **411** relative to the small diameter portion **359** of the connector portion **357**. The translational motion may open the seal between the end **361** and the small diameter portion **359** due to the difference in diameters between the end **361** and the small diameter portion **359** to allow fluid flow between the chamber **410** and the opening **411**.

Sub-housing **409b** may comprise a socket segment **456** connected to a connector segment **457**. The socket segment **456** may comprise an opening **412** configured to receive a fluid pathway, e.g., a length of tubing. The opening **412** may be in communication with a chamber **414** formed by the socket segment **456** and the connector segment **457**. The connector segment **457** may comprise a small diameter portion **459** disposed between the chamber **414** and an opening **415** of the connector segment **457**. Communication between the opening **412** of the socket portion **456** and the chamber **414** may be effected by a hollow channel **362** that

extends from the opening **412** of the socket portion **456** through the chamber **414** past the small diameter portion **459** and is blocked at an end **461**. The channel **362** may comprise at least one orifice **460** disposed within the chamber **414** that allows fluid communication between the opening **412** and the chamber **414**. The end **461** of the channel **362** may cover the small diameter portion **459** such that the end **461** and the small diameter portion **459** form a hermetic seal separating the chamber **414** and the opening **415** when the first sub-housing is in a closed configuration. The diameter of the end **461** disposed on the chamber side of the small diameter portion **459** may be smaller than the diameter of the small diameter portion **459**, while the diameter of the end **461** disposed on the side of the opening **415** may be larger than the diameter of the small diameter portion **459**. The differences in diameters of the end **461** of the channel **362** may ensure that the end **461** does not retract back into the chamber **414**.

An open configuration of the second sub-housing **409b** may be effected by rotation of the socket segment **456** and connector segment **457** relative to each other. In one embodiment, the channel **362** may have outer threads **458a** configured to mate with corresponding inner threads **457a** of the connector portion **457** such that in the closed configuration of the sub-housing **409b**, outer and inner threads **458a** and **457a** are tightly fastened, with the end **461** tightly sealed against the small diameter portion **459**. Rotation of the socket segment **456** and connector segment **457** relative to each other may induce translational motion of the channel **362** and end **461** towards the opening **415** relative to the small diameter portion **459** of the connector portion **457**. The translational motion may open the seal between the end **461** and the small diameter portion **459** due to the difference in diameters between the end **461** and the small diameter portion **459** to allow fluid flow between the chamber **414** and the opening **415**.

Referring now to FIG. 6B, a longitudinal cross section view of the connector **350** is shown in which sub-housings **409a** and **409b** are engaged with each other in sealing engagement, according to an exemplary embodiment. FIG. 6B depicts both sub-housings **409a** and **409b** in closed configurations. The opening **411** of the connector segment **357** of the sub-housing **409a** and the opening **415** of the connector segment **457** of the sub-housing **409b** may be configured to form an enclosed chamber **416**. The inner surface **411a** of the connector portion **357** forming the opening **411**, the end **361** of the channel **358**, and/or the end **461** of the channel **362** may together form the walls of the enclosed chamber **416**. The connector segments **357** and **457** may be configured such that the outer surface of one segment forms a friction fit, interference fit, Luer fit, threaded fit, etc., with the other segment. For example, the outer surfaces **415b** (FIG. 6A) of the connector segment **357** may be configured to hermetically engage with the inner surfaces **415a** of the connector segment **457**. Once the chamber **416** is hermetically sealed, surfaces **411a**, **361**, **461** previously open to the atmosphere may be sterilized as described previously in reference to FIG. 4.

It may be desirable to selectively apply sterilization energy to the chamber **416** while minimizing exposure of the germicidal dose of energy to other portions of the connector **350**. For example, the socket portion **356** of sub-housing **409a** and the socket segment **456** of sub-housing **409b** and any fluid contained therein may not require sterilization and may comprise biological materials sensitive to the sterilization energy. Therefore, it may be desirable for the socket portions **356** and **456** to comprise a material with low

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permeability to the sterilization energy and for the connector portions **357** and **457** to comprise a material with high permeability to the sterilization energy. In an embodiment in which the sterilization energy source comprises UVC, the connector portions **357** and **457** may comprise a substantially UVC-transparent material, such as cyclic olefin copolymer (COC), poly(methyl methacrylate) (PMMA), polymethylpentene (PMP or TPX), and/or quartz glass, and the socket portions **356** and **456** may comprise a substantially UVC-opaque material, such as polycarbonate, PVC, and/or ABS. In an embodiment in which the sterilization energy source comprises heat, steam, ebeam, gamma rays, etc., the connector portions **357** and **457** may comprise a heat conductive material, such as polycarbonate, PVC, and/or ABS, and the socket portions **356** and **456** may further comprise a substantially heat transmissive material and may even comprise heat resistive material, such as polyurethane and/or silica aerogel. Referring to FIG. 6A, in one embodiment, connector portions **357** and **457** may be made of one material permeable to the sterilization energy for a segment **217** surrounding the sterilization chamber **416** and another material less permeable to the sterilization energy for the remaining portions of connector portions **357** and **457**.

Referring to FIG. 7, once the chamber **416** and corresponding surfaces **411a**, **361**, **461** (FIG. 6B) have been sterilized, fluid communication may be opened between chambers **410** and **416**. Sub-housing **409a** may be shifted to an open configuration by rotating the socket segment **356** and connector segment **357** relative to each other. Rotation may induce translational motion of the channel **358** and end **361** towards the opening **411** relative to the small diameter portion **359** of the connector portion **357**. The translational motion may open the seal between the end **361** and the small diameter portion **359**. Fluid from the sub-housing **409a** may flow from within the channel **358** through the orifice **360** into the chamber **410** past the small diameter portion **359** and into the sterilization chamber **416**. Sub-housing **409b** may likewise be shifted to an open configuration by rotating the socket segment **456** and connector segment **457** relative to each other. Rotation may induce translational motion of the channel **362** and end **461** towards the opening **415** relative to the small diameter portion **459** of the connector portion **457**. The translational motion may open the seal between the end **461** and the small diameter portion **459**. Fluid from the sterilization chamber **416** may flow through the small diameter portion **359** into the chamber **414** and into the orifice **460** of the channel **362**.

In one embodiment, the socket portions **356**, **456** may incorporate O-rings **335** disposed between outer threads **358a**, **458a** and the chambers **410**, **414** to prevent leakage of fluid from chambers **410**, **414** into the space between the socket portions **356**, **456** and the connector portions **357**, **457**. In one embodiment, shifting the connector **350** into the open configuration via rotation of socket portions **356** and **456** relative to the connector portions **357** and **457** may be induced simultaneously by fixing the socket portions **356** and **456** in place and rotating the connector portion **457**. The engagement (friction fit, interference fit, Luer fit, threaded fit, etc.) between the connector segments **357** and **457** may induce connector segment **357** to rotate along with segment **457**. The outer surface **415c** (FIG. 7) of the connector portion **457** may comprise an outer diameter larger than the rest of the connector portion **457**. The outer surface **415c** may also comprise gears **415d**, as shown in FIG. 8, and may be rotated by a device having complementary gears. In one embodiment, the device providing the sterilization energy source **300** (FIG. 4) may comprise a mold configured to

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receive the connector **350**, engage the sub-housings **409a** and **409b**, apply the sterilization energy source, hold the socket portions **356** and **456** in place, and shift both sub-housings **409a** and **409b** into open configurations simultaneously by rotating the outer surface **415c** while holding the socket portions **356** and **456** in place.

Without limiting the foregoing description, in accordance with one aspect of the subject matter herein, there is provided a tube connector for a fluid circuit system comprising a housing. A first opening is configured to receive a first length of tubing in communication with a first chamber. A second opening is configured for communicating with the first chamber when the tube connector is in an open configuration but not in a closed configuration. A third opening is configured to receive a second length of tubing in communication with a second chamber. A fourth opening is configured for communicating with the second chamber when the tube connector is in the open configuration but not in the closed configuration. The second opening and the fourth opening are configured to engage each other to form a third chamber.

In accordance with a second aspect which may be used or combined with the immediately preceding aspect, the housing comprises a first sub-housing comprising the first opening, the second opening, and the first chamber. A second sub-housing comprises the third opening, the fourth opening, and the second chamber. At least a portion of the first and/or second sub-housings comprises a material comprising at least one of cyclic olefin copolymer (COC), poly(methyl methacrylate), polymethylpentene, and quartz glass.

In accordance with a third aspect which may be used or combined with the immediately preceding aspect, the first and second sub-housings each comprises a connector portion and a socket portion, and the tube connector is configured to shift from a closed configuration to an open configuration when the connector portions are rotated relative to the socket portions.

In accordance with a fourth aspect which may be used or combined with any of the preceding aspects, the tube connector is configured to shift from a closed configuration to an open configuration when the second or fourth opening is translationally shifted relative to the first or third opening.

In accordance with a fifth aspect which may be used or combined with any of the preceding aspects, the tube connector is configured to shift from a closed configuration to an open configuration when the first and/or second chamber is translationally shifted relative to the third chamber.

In accordance with a sixth aspect which may be used or combined with any of the preceding aspects, the second opening and the fourth opening are configured to engage each other in at least one of a friction fit, an interference fit, a Luer fit, and a threaded fit to form the third chamber.

In accordance with a seventh aspect which may be used or combined with any of the preceding aspects, the connector portion of the first or second sub-housings further comprises a geared outer surface, which rotation is configured to simultaneously rotate both connector portions relative to both socket portions when the socket portions are fixed in place.

In accordance with an eighth aspect, there is provided a method of sterilely connecting two fluid pathways. Provided is a first connector comprising a first chamber and a first open end and configured to connect to a first fluid pathway. The first chamber is configured to communicate with the first fluid pathway and the first open end when the first connector is in an open configuration but not in a closed

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configuration. Provided is a second connector comprising a second chamber and a second open end and configured to connect to a second fluid pathway. The second chamber is configured to communicate with the second fluid pathway and the second open end when the second connector is in an open configuration but not in a closed configuration. The first open end and the second open end are configured for engagement to form a third chamber. The third chamber is configured to communicate with the first chamber when the first connector is in the open configuration but not in the closed configuration and communicate with the second chamber when the second connector is in the open configuration but not in the closed configuration. The first open end and the second open end forming the third chamber comprises a first material at least partially permeable to a sterilization energy source for sterilizing contents of the third chamber. A first portion of the first connector surrounding the first chamber and a second portion of the second connector surrounding the second chamber comprise a second material less permeable to the sterilization energy source. Applying the sterilization energy source to the third chamber upon engagement of the first and second open ends when the first and second connectors are in the closed configuration and subsequently opening the first and second connectors to the open configuration allows sterile fluid from the first chamber to cross the third chamber into the second chamber while maintaining sterility.

In accordance with a ninth aspect which may be used or combined with the immediately preceding aspect, the sterilization energy source comprises a UVC emitter and the first material comprises at least one of cyclic olefin copolymer, poly(methyl methacrylate), polymethylpentene, and quartz glass. Otherwise, the sterilization energy source comprises at least one of heat, steam, ebeam, and gamma rays and the second material comprises polyurethane and/or silica aerogel.

In accordance with a tenth aspect, which may be used or combined with any of the eighth or ninth aspects, the first and second connectors each comprises a connector portion and a socket portion. The first connector is configured to shift from the closed configuration to the open configuration when the connector portion of the first connector is rotated relative to the socket portion of the first connector. The second connector is configured to shift from the closed configuration to the open configuration when the connector portion of the second connector is rotated relative to the socket portion of the second connector.

In accordance with an eleventh aspect which may be used or combined with any of the eighth through tenth aspects, the first or second connector is configured to shift from the closed configuration to the open configuration when the first or second open end is translationally shifted relative to the first or second fluid pathway.

In accordance with a twelfth aspect which may be used or combined with the any of the eighth through eleventh aspects, the first or second connector is configured to shift from the closed configuration to the open configuration when the first or second chamber is translationally shifted relative to the third chamber; or when the first or second chamber is translationally shifted relative to the first or second fluid pathway.

In accordance with a thirteenth aspect which may be used or combined with any of the eighth through twelfth aspects, the first and second open ends are configured to engage each other in at least one of a friction fit, an interference fit, a Luer fit, and a threaded fit to form the third chamber.

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In accordance with a fourteenth aspect which may be used or combined with any of the twelfth and thirteenth aspects, the first and second connectors each comprises a connector portion and a socket portion. The first or second chamber is translationally shifted relative to the third chamber or to the first or second fluid pathway by rotating the connector portion of the first connector relative to the socket portion of the first connector and by rotating the connector portion of the second connector relative to the socket portion of the second connector.

In accordance with a fifteenth aspect, there is provided a sterile tube connector for a fluid circuit system comprising a housing. A first opening is configured to receive a first length of tubing in communication with a first chamber. A second opening is configured for communicating with the first chamber when the tube connector is in an open configuration but not in a closed configuration. The second opening is configured to reversibly engage a third opening to form a second chamber. The third opening is configured for communicating with a second length of tubing. A first portion of the housing forming the first opening comprises a material at least partially permeable to a sterilization energy source for sterilizing contents of the second chamber.

In accordance with a sixteenth aspect, which may be used or combined with the fifteenth aspect, a second portion of the housing forming the first opening comprises a material less permeable to the sterilization energy source.

In accordance with a seventeenth aspect which may be used or combined with any of the fifteenth and sixteenth aspects, the material comprises at least one of cyclic olefin copolymer, poly(methyl methacrylate), polymethylpentene, and quartz glass, and the sterilization energy source comprises UVC.

In accordance with an eighteenth aspect which may be used or combined with any of the sixteenth and seventeenth aspects, the material of the second portion comprises polyurethane and/or silica aerogel and the sterilization energy source comprises at least one of heat, steam, ebeam, and gamma rays.

In accordance with a nineteenth aspect, which may be used or combined with any of the fifteenth through eighteenth aspects, the housing further comprises a connector portion and a socket portion, and the tube connector is configured to shift from the closed configuration to the open configuration when the connector portion is rotated relative to the socket portion.

In accordance with a twentieth aspect which may be used or combined with any of the fifteenth through nineteenth aspects, the tube connector is configured to shift from the closed configuration to the open configuration when a linear force is applied to the tube connector in a direction parallel to the first length of tubing.

The embodiments disclosed herein are for the purpose of providing a description of the present subject matter, and it is understood that the subject matter may be embodied in various other forms and combinations not shown in detail. Therefore, specific embodiments and features disclosed herein are not to be interpreted as limiting the subject matter as defined in the accompanying claims.

The invention claimed is:

1. A tube connector for a fluid circuit system moveable between a closed configuration and an open configuration comprising: a housing comprising: a first sub-housing having a first opening configured to receive a first length of tubing in communication with a first chamber and a second opening configured for communicating with the first chamber when the tube connector is in the open configuration but

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not in the closed configuration; a second sub-housing having a third opening configured to receive a second length of tubing in communication with a second chamber and a fourth opening configured for communicating with the second chamber when the tube connector is in the open configuration but not in the closed configuration; each of the first and second sub-housings having a connector segment and a socket segment configured to directly secure one of the respective lengths of tubing thereto, with the socket segment being movable relative to the connector segment for the first sub-housing to move the tube connector between the closed and open configurations, and the socket segment being immovably fixed to the connector segment for the second sub-housing, wherein the second opening and the fourth opening are configured to engage each other to form a third chamber that communicates with the first chamber and the second chamber when the tube connector is in the open configuration but not when in the closed configuration.

2. The tube connector of claim 1, wherein at least a portion of the first and/or second sub-housings comprises a material comprising at least one of cyclic olefin copolymer (COC), poly(methyl methacrylate), polymethylpentene, and quartz glass.

3. The tube connector of claim 1, wherein the tube connector is configured to shift from a closed configuration to an open configuration when the second or fourth opening is translationally shifted relative to the first or third opening.

4. The tube connector of claim 1, wherein the tube connector is configured to shift from a closed configuration to an open configuration when the first and/or second chamber is translationally shifted relative to the third chamber.

5. The tube connector of claim 1, wherein the second opening and the fourth opening are configured to engage each other in at least one of a friction fit, an interference fit, a Luer fit, and a threaded fit to form the third chamber.

6. A sterile tube connector for a fluid circuit system moveable between a closed configuration and an open configuration comprising a housing comprising: a first sub-housing having a first opening configured to receive a first length of tubing in communication with a first chamber and a second opening configured for communicating with the first chamber when the tube connector is in the open configuration but not in the closed configuration; a second sub-housing having a third opening configured to receive a second length of tubing in communication with a second chamber; wherein the second opening is configured to reversibly engage the third opening to form a second chamber; each of the first and second sub-housings having a connector segment and a socket segment configured to directly secure one of the respective lengths of tubing

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thereto, with the socket segment being movable relative to the connector segment for the first sub-housing to move the tube connector between the closed and open configurations and the socket segment being immovably fixed to the connector segment for the second sub-housing, wherein a first portion of the housing forming the first opening comprises a material at least partially permeable to a sterilization energy source for sterilizing contents of the second chamber.

7. The sterile tube connector of claim 6, wherein a second portion of the housing forming the first opening comprises a material less permeable to the sterilization energy source.

8. The sterile tube connector of claim 6, wherein the material comprises at least one of cyclic olefin copolymer, poly(methyl methacrylate), polymethylpentene, and quartz glass, and the sterilization energy source comprises UV-C light.

9. The sterile tube connector of claim 7, wherein the material of the second portion comprises polyurethane and/or silica aerogel and the sterilization energy source comprises at least one of heat, steam, electron beam, and gamma rays.

10. The sterile tube connector of claim 6, wherein the tube connector is configured to shift from the closed configuration to the open configuration when a linear force is applied to the tube connector in a direction parallel to the first length of tubing.

11. The tube connector of claim 1 wherein the socket segment of one of the first and second sub-housings has a stopper associated therewith for selective engagement with a valve associated with the connector segment of its respective sub-housing, the stopper being mounted to a compressible member and having a tapered side wall, and the valve comprising a surface defining an aperture, the tapered side wall of the stopper being spaced from the surface defining the aperture to permit flow through the valve when in the open configuration and to engage the surface defining the aperture to prevent flow through the valve when in the closed configuration.

12. The sterile tube connector of claim 6 wherein the socket segment of one of the first and second sub-housings has a stopper associated therewith for selective engagement with a valve associated with the connector segment of its respective sub-housing, the stopper being mounted to a compressible member and having a tapered side wall, and the valve comprising a surface defining an aperture, the tapered side wall of the stopper being spaced from the surface defining the aperture to permit flow through the valve when in the open configuration and to engage the surface defining the aperture to prevent flow through the valve when in the closed configuration.

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